Beam-beam coherent modes in the LHC

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Acknowledgments to G. Arduini and the LHC and injectors OP crews

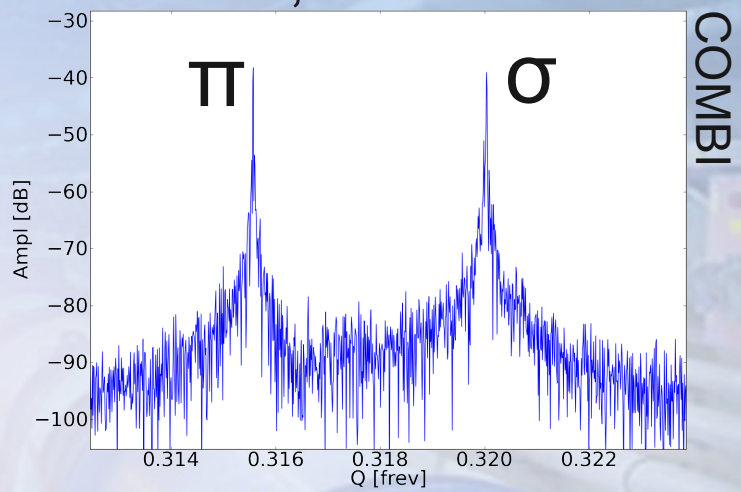
Beam-beam coherent mode in the LHC

- Introduction
- Observation of coherent modes
  - Stable
    - Dedicated experiment
    - Standard operation
  - Unstable
    - Dedicated experiment
    - Standard operation

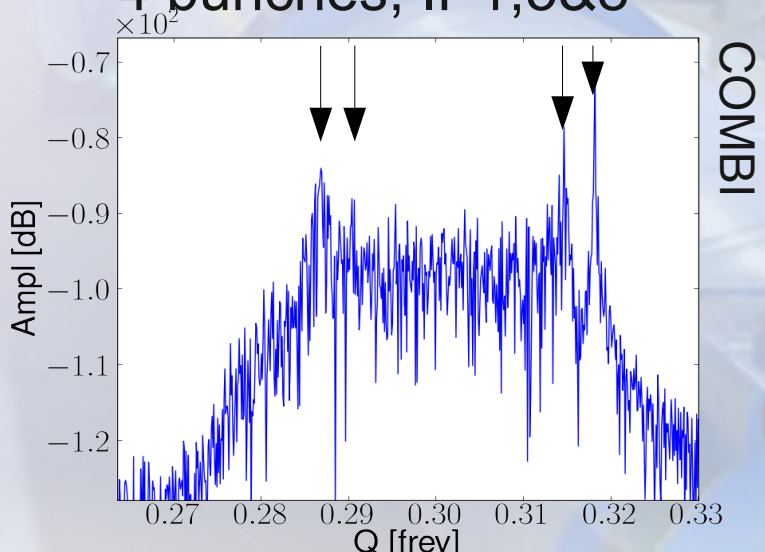
Coherent modes in the LHC
single bunches

- One bunch and one IP
  - Two oscillation modes
- Other modes appear with other more IPs and bunches
  - They can be degenerated because of the symetry, e.g. IP1 and 5

1bunch,1IP :

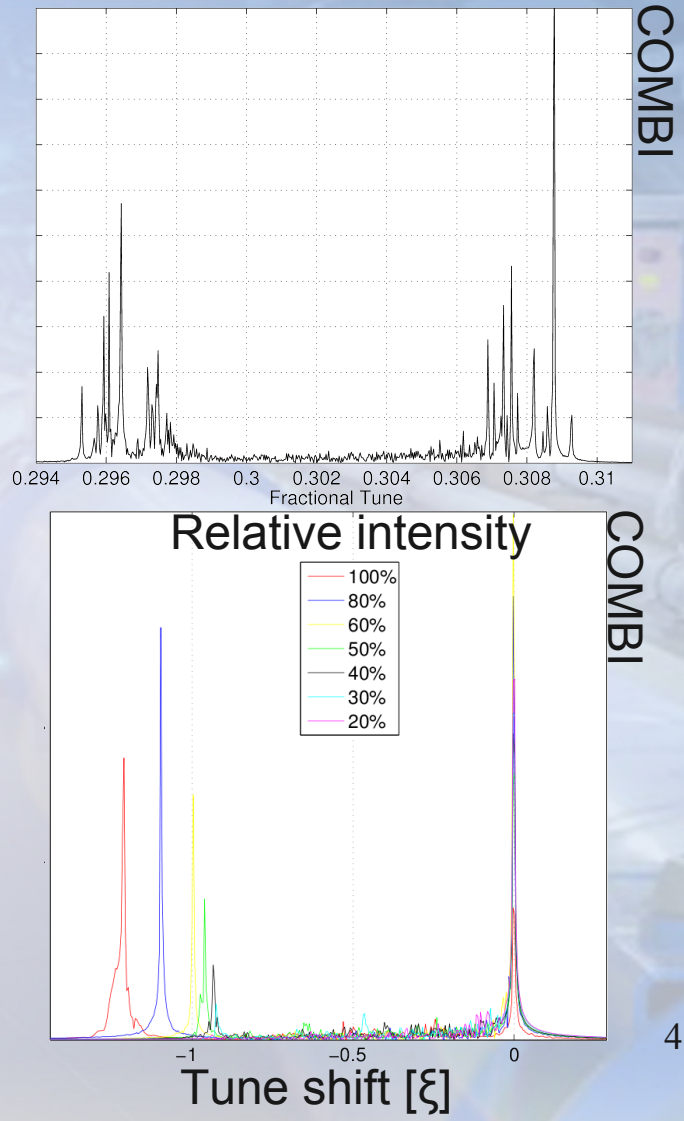


4 bunches, IP1,5&8



Coherent modes in the LHC
multibunch

- In the multibunch regime, most modes lie in the incoherent spectrum and are not visible
- Symetry breaking parameters (variation in the bunch parameters, phase advance between the IPs) tends to bring the modes frequencies in the incoherent spectrum
- In some cases, frequencies outside the incoherent spectrum could be expected

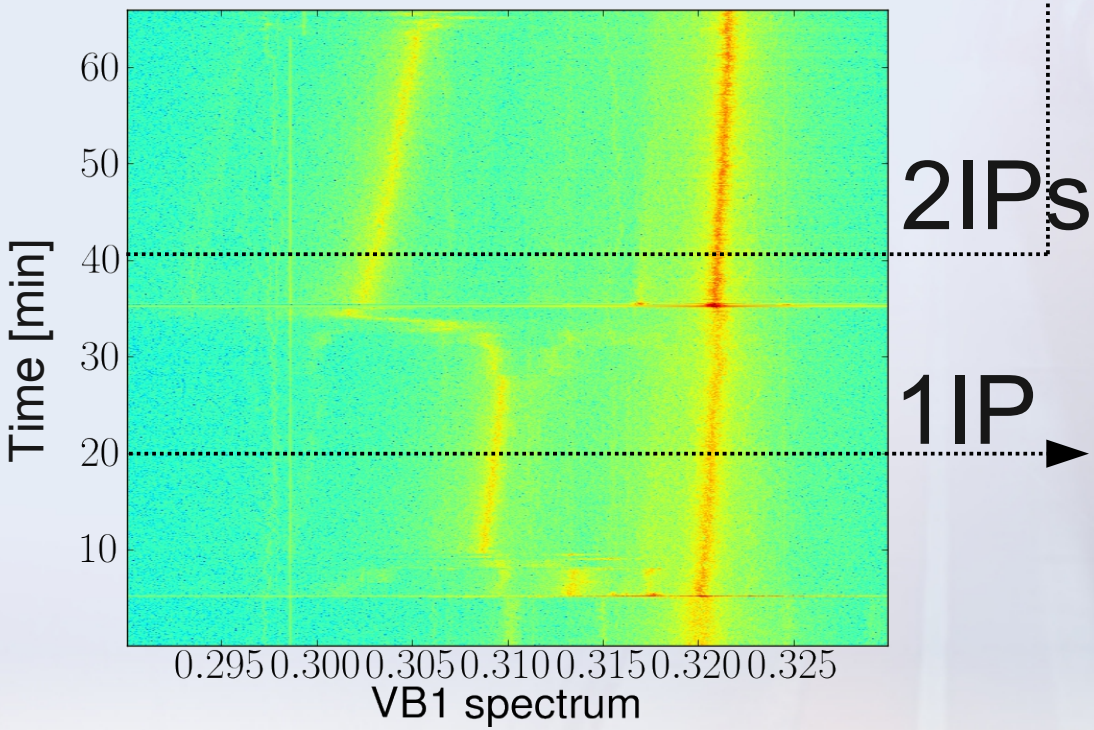


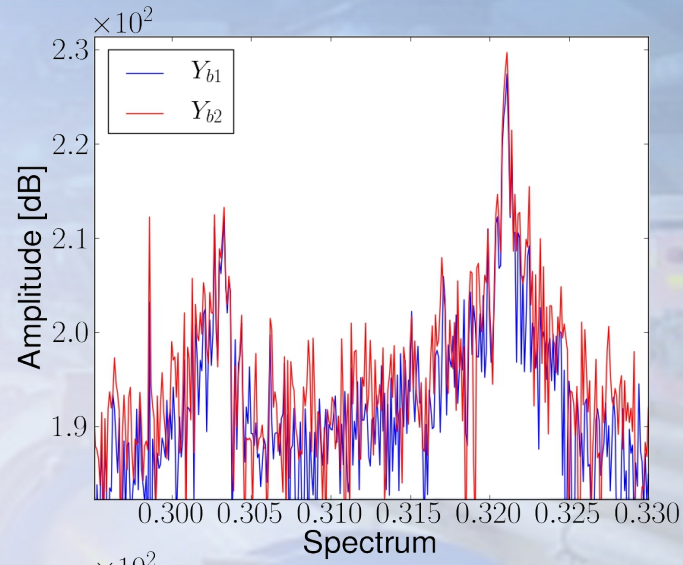
Observations

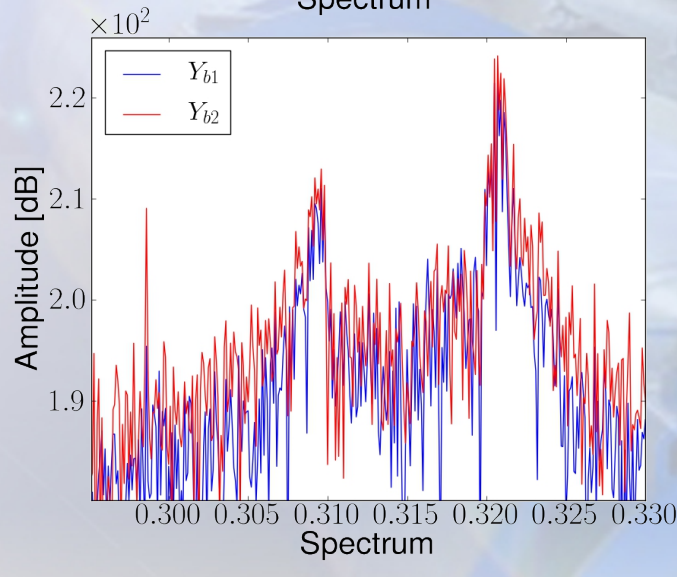
- Beam-beam modes observed during commissioning with single bunches (early 2010)
  - No longer observed with bunch trains
- Parasitic observation during head-on beam-beam MDs, early 2011
  (Aiming at probing maximum head-on tune shift achievable)
  - In total 6 fills with different beam brightness (with ξ up to 0.017 per IP and two IPs)
  - Coherent modes were always visible on the BBQ
- Coherent modes could also be observed parasitically in other MDs with single bunches :
  - High pile-up (2011)
  - Beam-beam and external noise (late 2012)

Stable single bunch mode in dedicated experiment

- Single bunch, 450 GeV
  - ξ~0.01 per IP
  - Modes are visible but usually stable
  - Transverse feedback is off

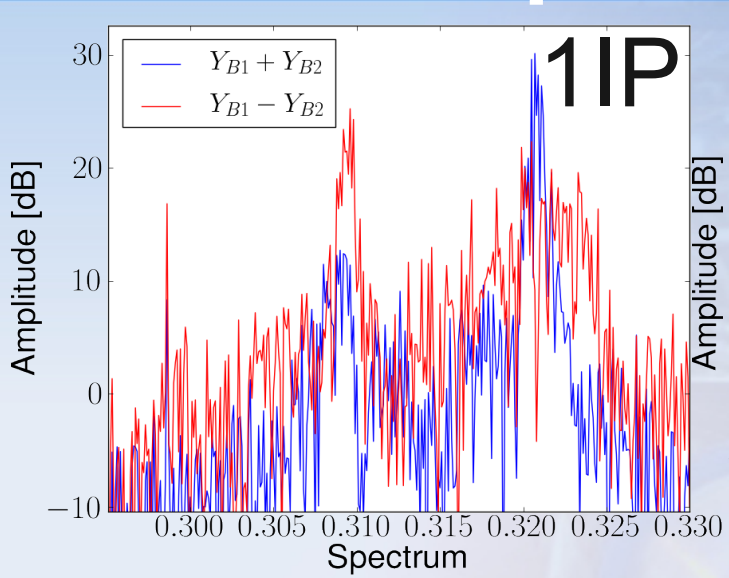


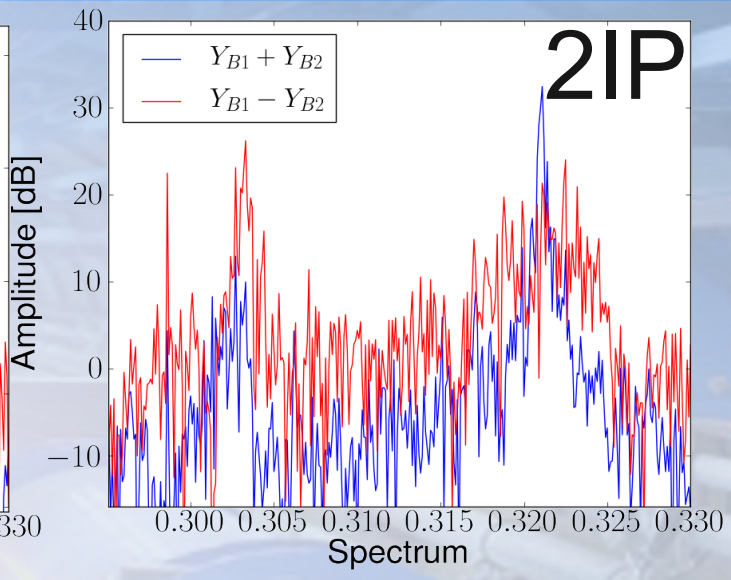




Stable single bunch mode in dedicated experiment

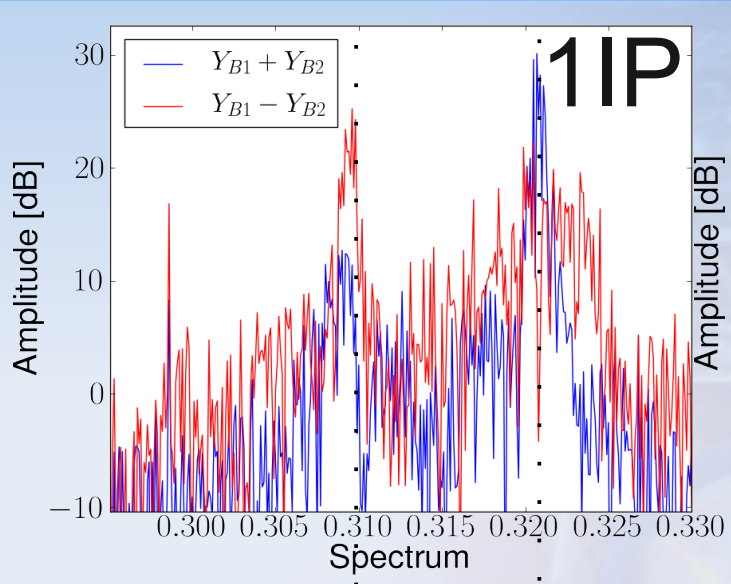
- SVD of turn by turn data from the BBQ shows the expected σ and π modes

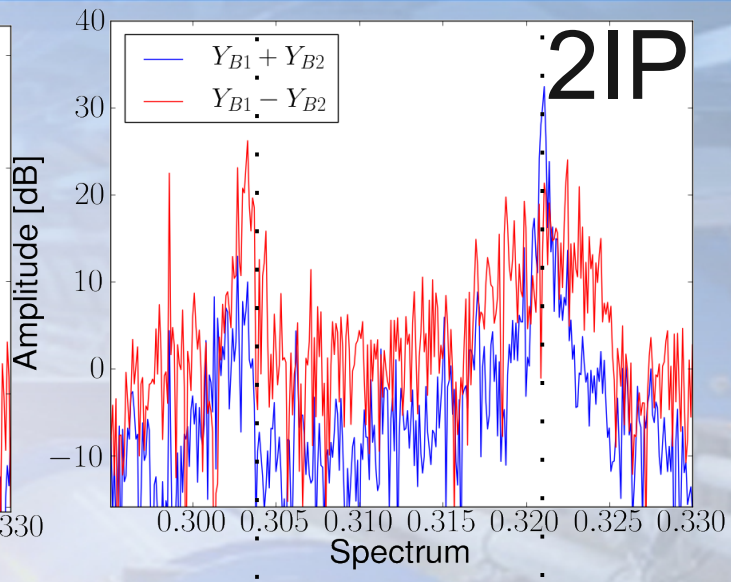


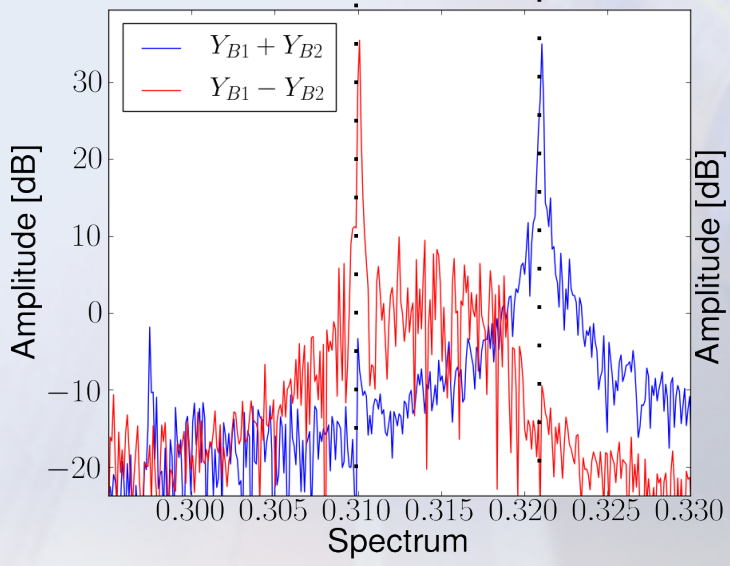


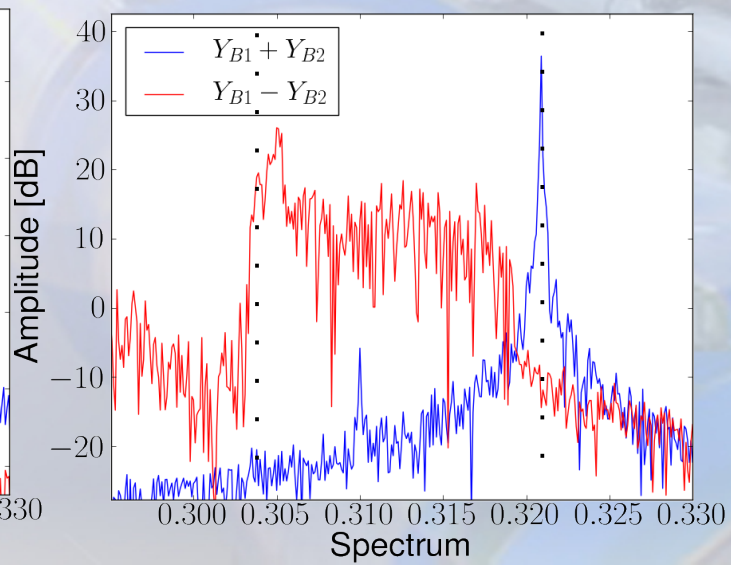
Comparison with simulation

- Bunch parameters are too different to measure the Yokoya factor
- Good agreement with self-consistent multiparticle tracking (COMBI)
  - Measured tunes, intensities and emittances used as input



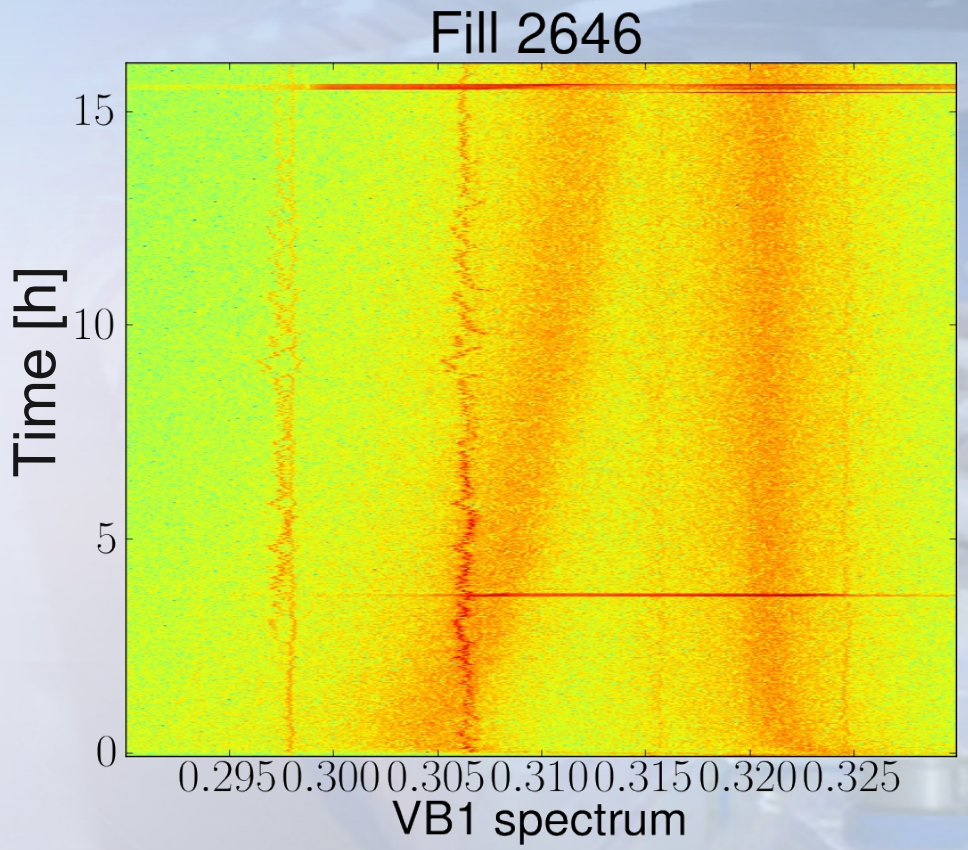






Stable modes during luminosity production

- A coherent signal is visible during luminosity production
- Transverse feedback is on
- Only ADT pickups are capable of providing bunch by bunch turn by turn data, but only 72 turns
  - Multibunch modes can have complex patterns, not resolvable with such small data sample
- Not distinguishable from incoherent spectrum on the BBQ

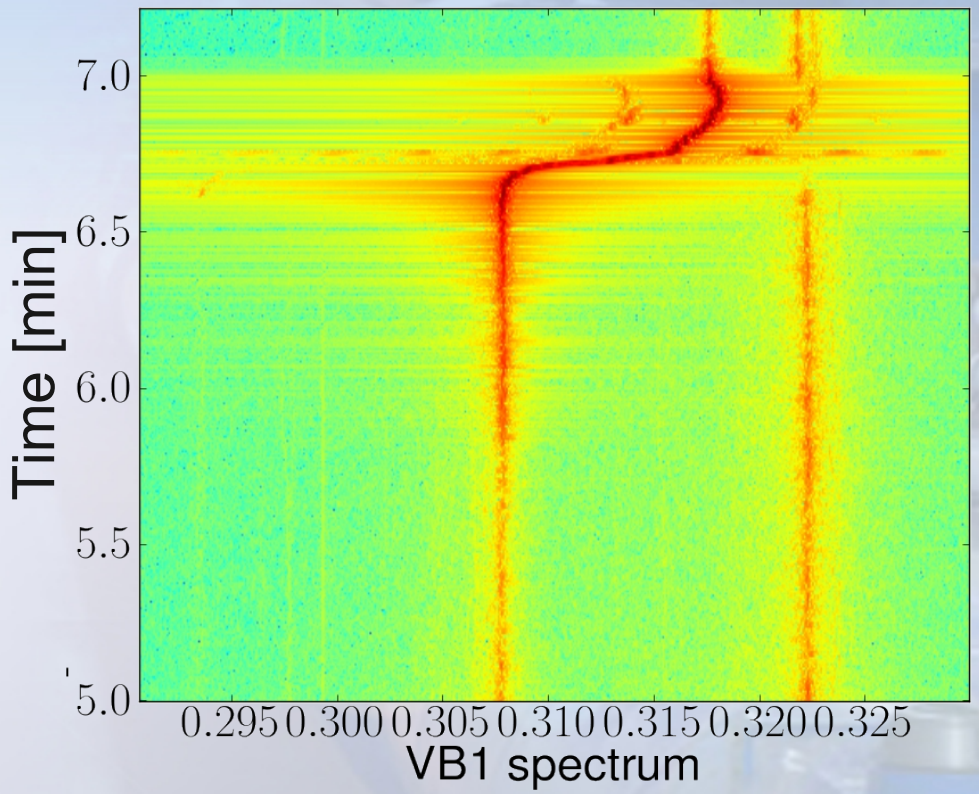


Summary
stable beam -beam modes

- Beam-beam coherent modes have been observed in the LHC with single bunches in dedicated experiment with single/few bunches
  - They are usually stable, even with high beam-beam tune shift
- A coherent signal is visible in the BBQ at frequencies around Q-ξ, not distinguishable from incoherent spectrum
  - Improved diagnostics are required to make full analysis of multibunch coherent modes
- No time was allocated to study intermediate configurations
  - 3-4 IPs, few bunch trains, ...

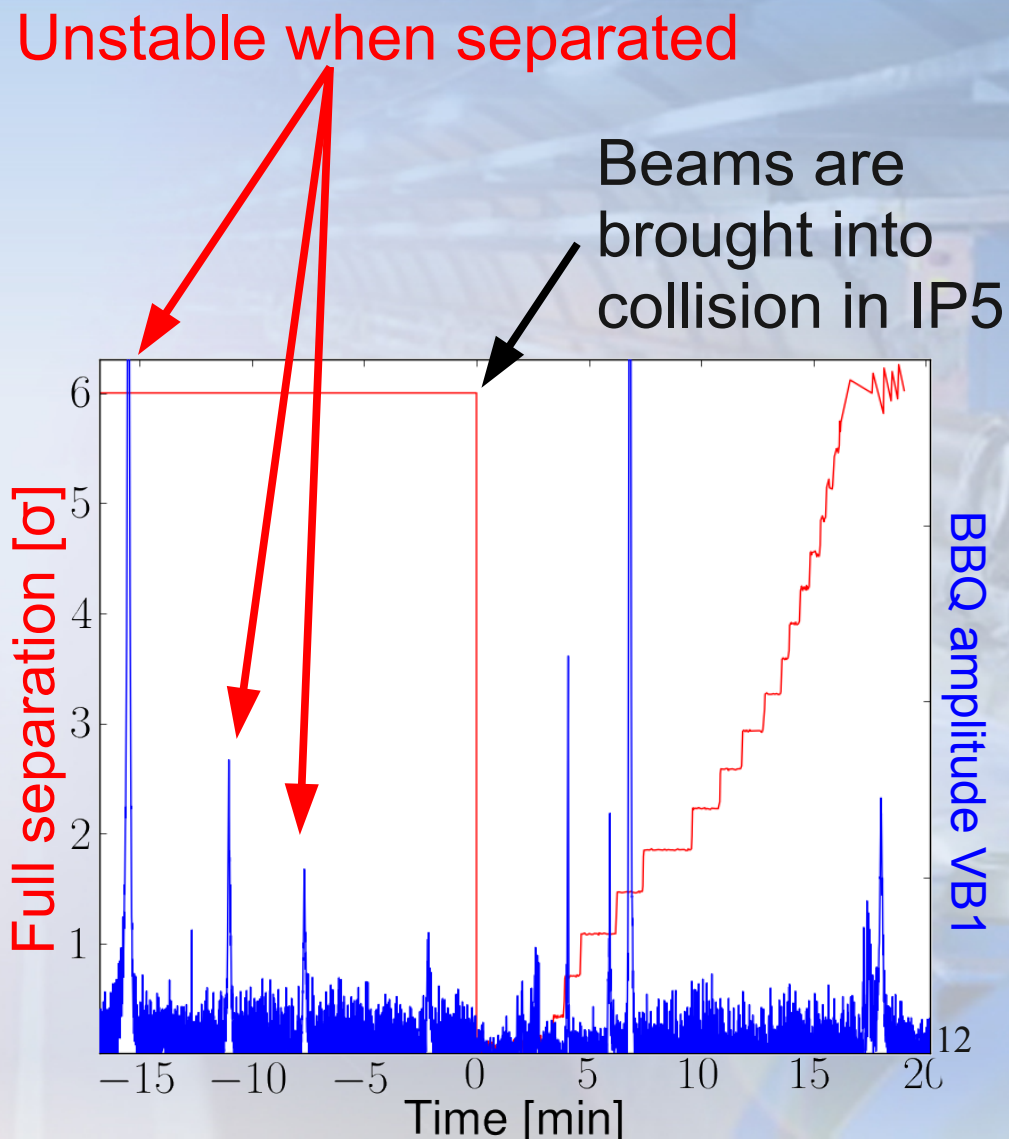
Observations of single bunch instability

- A strong coherent instability was observed during an experiment with high beam-beam tune shift (Injection energy, transverse feedback off, single bunch colliding in IP1 and 5, ξ~0.01)
- π mode moves towards the σ mode as the beams brightness goes down
- The driving force of the instability is not understood
  - No chromaticity measurement available



Stability of beams colliding with a transverse offset

- Two bunches per beam colliding in IP1&5
  - IP1 remains separated by 6σ
- After the squeeze
- Full octupole strength
- Nominal tunes
- Chromaticity ~ 5
- Transverse feedback turned on only to save the beams every time an instability is detected



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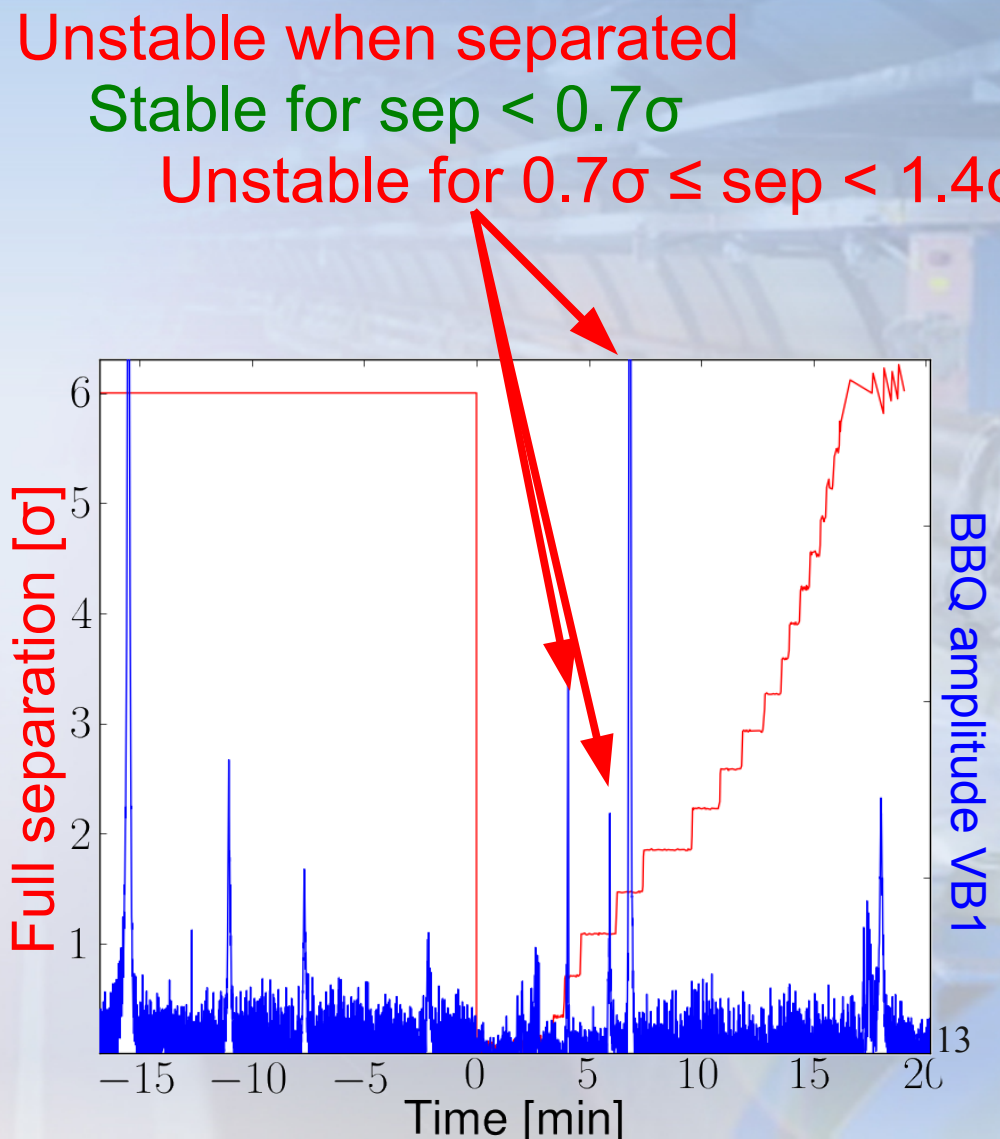

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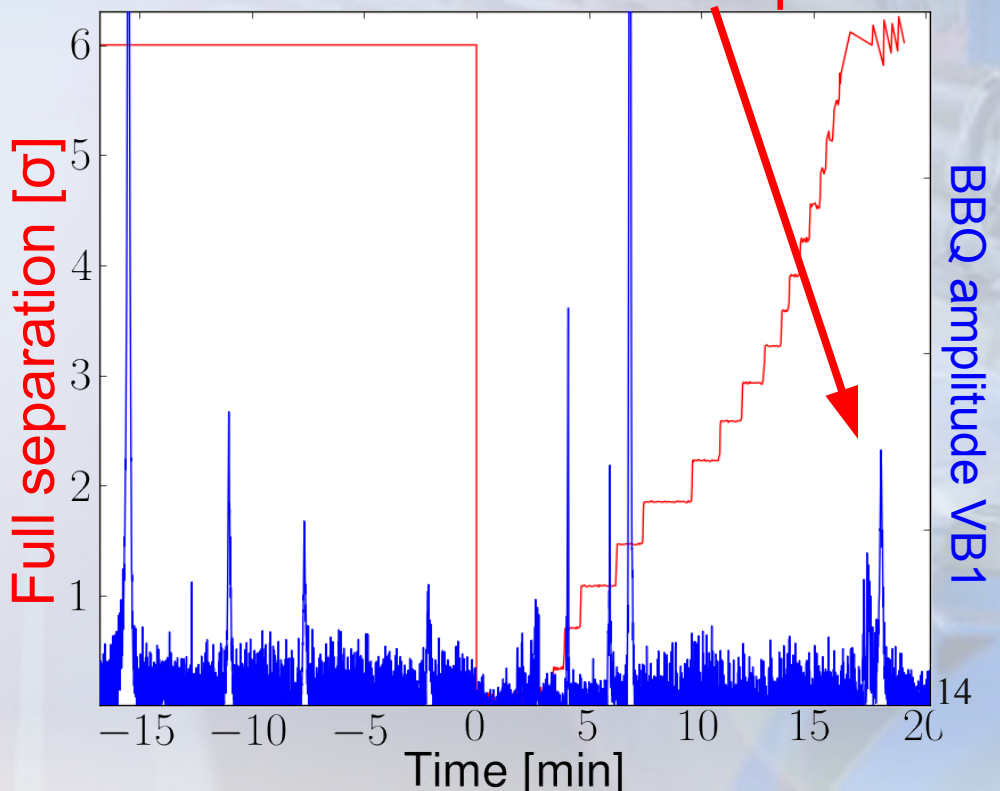
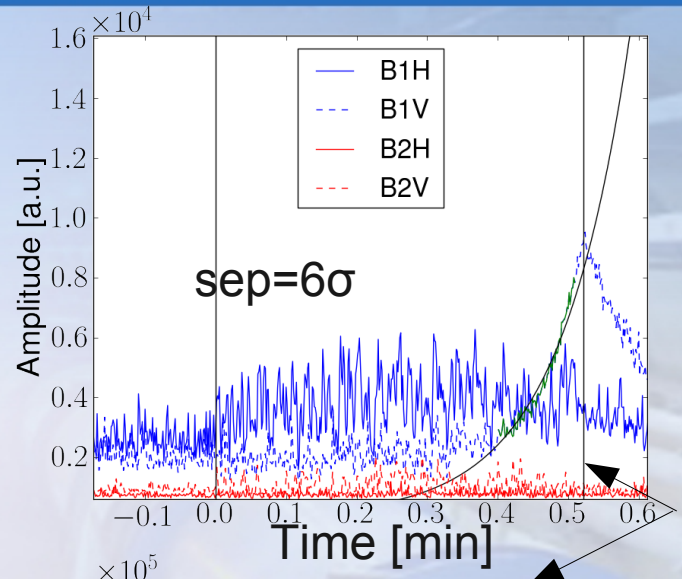
Unstable when separated
Stable for sep < 0.7σ
Unstable for 0.7σ ≤ sep < 1.4σ
Stable for1.4σ ≤ sep < 6.0σ
Unstable for sep = 6.0σ



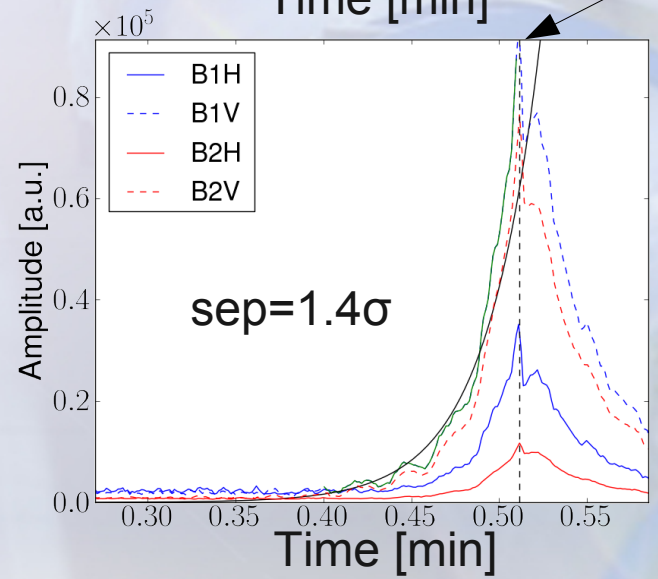
Stability of beams colliding with a transverse offset

- Instabilities with 6σ separation are single bunch
- Oscillation amplitude indicates that the two beams are strongly coupled at small separation

Full separation [σ]	Rise time [s]
0.7	2.7
1.1	6.7
1.4	1.8
6	5.9

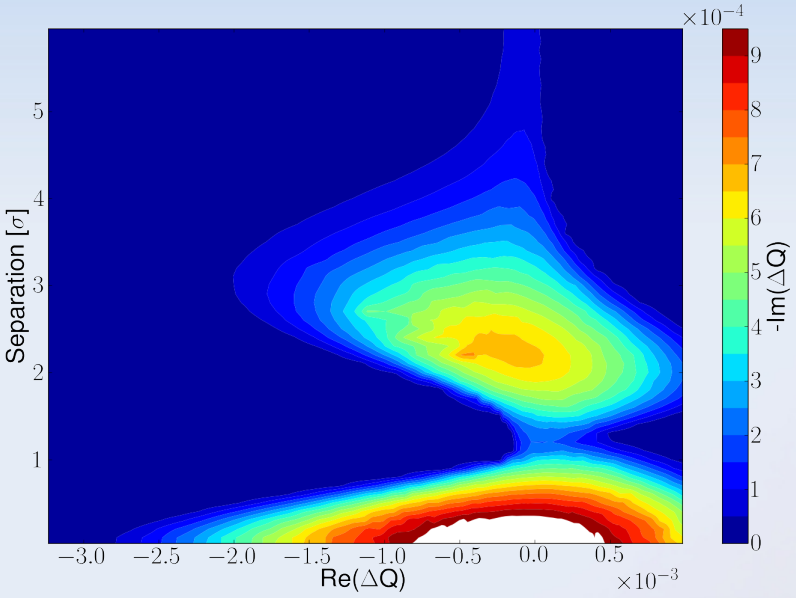


Transverse feedback is turned on

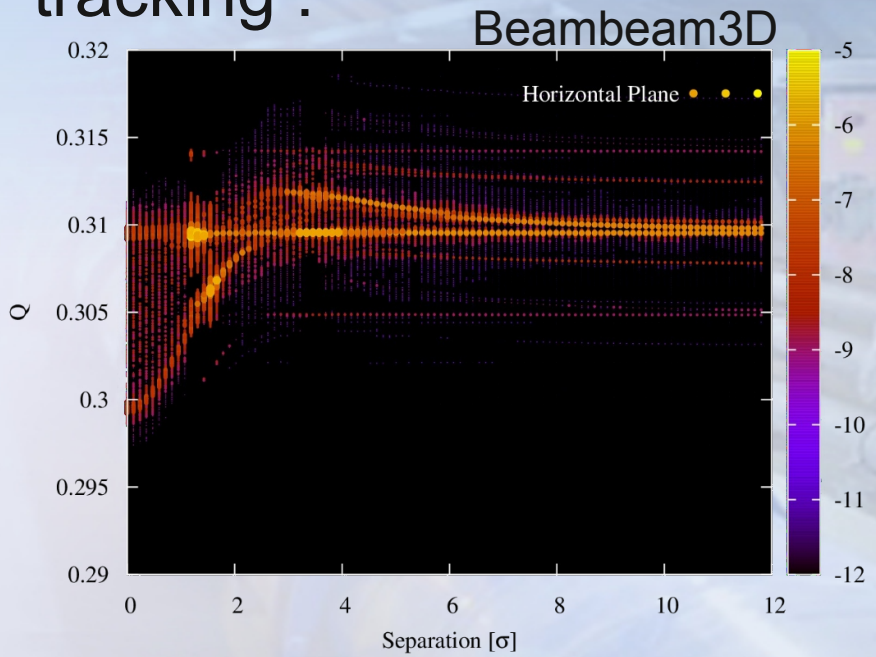


Comparison with models

- Pure impedance mode with beam-beam detuning :



- Self-constistent multiparticle tracking :

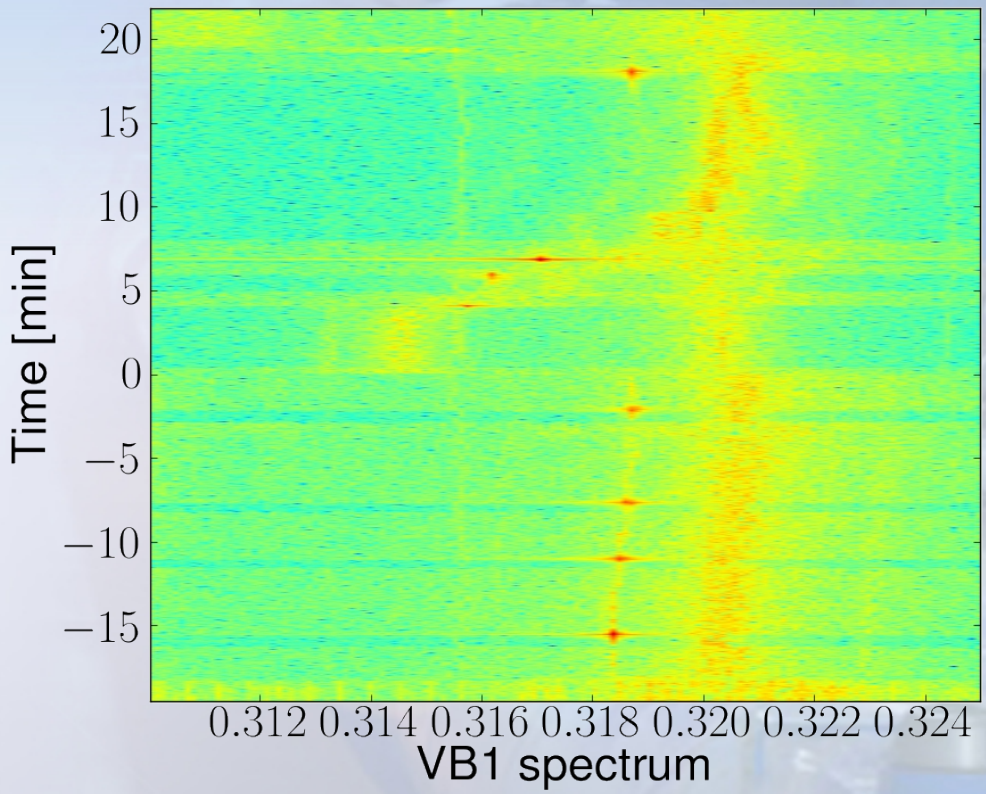


- Both models predict critical regions at small separation
- Quantitative comparison with experiments are not possible due to the too large uncertainty on the chromaticity

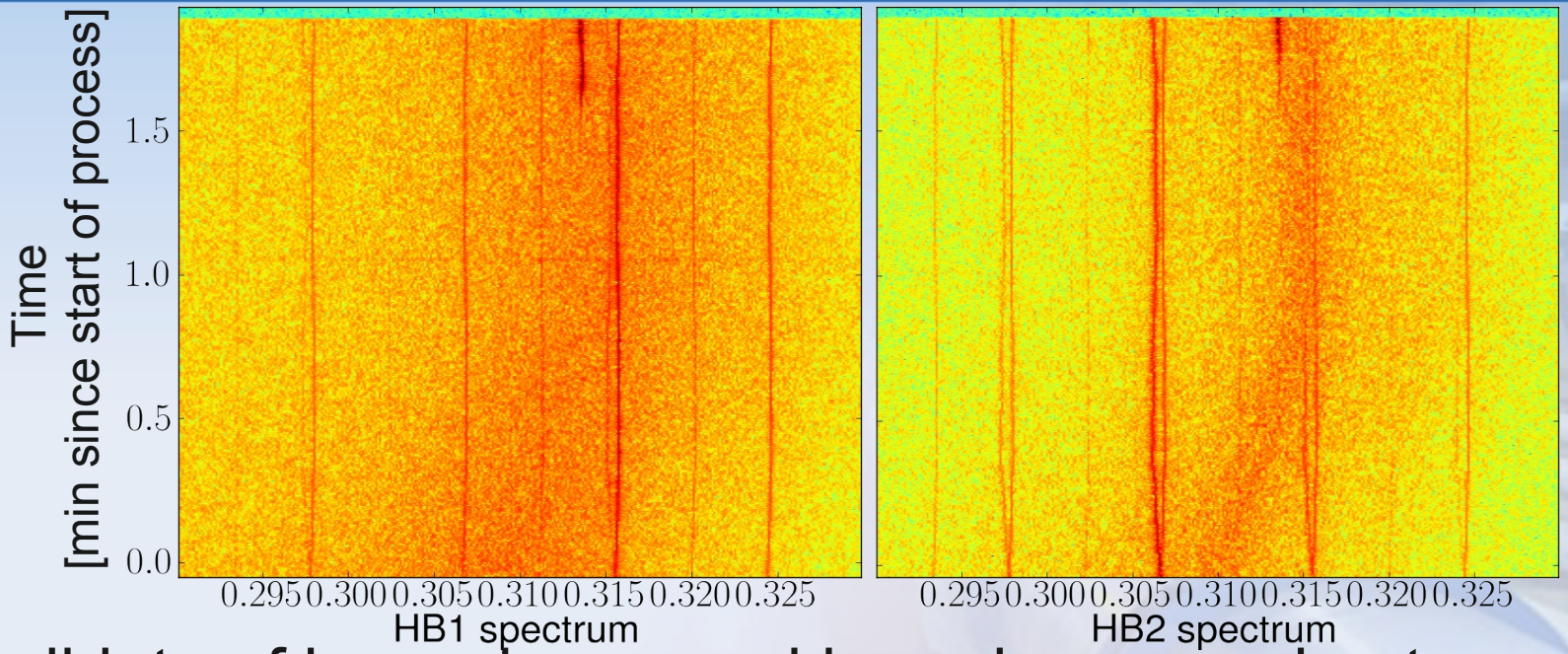
Stability of beams colliding with a transverse offset

- The frequency of the instabilities when the beams are separated is consitent with a head-tail mode -1 (Q_s=2.3E-3)
- With a small separation the tune shift is much larger and depends on the separation

  → consistent with coupled beam-beam and impedance mode



Coherent instabilities in standard operation



- Candidate of beam-beam and impedance mode at small separation while bringing the beams into collision (Fill 2808, July 2012)
- Not distinguishable from a single beam instability, with incoherent transimition of the signal to the other beam, via the beam-beam force (Using instrumentation available at the time)

Conclusion
Unstable coherent modes

- An experiment was performed to probe the stability of beams colliding with a small transverse offset, they are in qualitative agreement with models
  - The instabilities were always well damped by the transverse feedback
- During standard operation, no instability observed while colliding head-on
  - Candidate beam-beam – impedance instabilities have been observed and are under investigation
- Often, quantitative comparison with models are not possible due to lack of chromaticity measurement